

**UNCLASSIFIED**

---

**AD 401 079**

*Reproduced  
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY  
ARLINGTON HALL STATION  
ARLINGTON 12, VIRGINIA**



---

**UNCLASSIFIED**

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

# PROTECTION AGAINST RADIATION

- USSR -

[Following is a translation of an article by Ye. Romantsev in the Bol'shaya meditsinskaya entsiklopediya (Great Medical Encyclopedia), Vol. XXVI, Moscow, 1962, pages 1150-1168.]

Physical protection against radiation consists of a set of measures and facilities designed to protect the organism against radiation; regulation of radiation levels, use of guards, remotely and automatically controlled methods of work, and the appropriate technology. In setting up a system of protection against radiation, it is important to determine the limits of danger, i.e., to assess correctly the radiation levels that will be safe for man.

After extensive animal experimentation and analysis of the experience of persons working with X-rays and gamma rays, scientists decided that penetrating radiation in certain doses does not cause irreversible changes in the body. The largest dose that, in the light of modern knowledge, does not cause irreversible changes is called the maximum permissible dose (MPD).

The biological action of radiation depends not only on the size of the dose absorbed and relative biological effectiveness of different kinds of radiation, but also on the ways it acts on the human organism. Maximum permissible doses

**Best  
Available  
Copy**

are established accordingly for both external and internal radiation. Exposed to alpha or beta particles, gamma rays, or neutrons, man receives injury only as long as he is near the sources of radiation.

Working with radioactive substances of the open kind (packing, solution, preparation of tagged compounds, etc.) may disperse them with resultant contamination of the room, air, equipment, clothing, and hands. They can naturally penetrate the organism under these circumstances. The radiation emitted, unlike external radiation, irradiates the area for a long time until the radioactive substances are eliminated from the body either through decay or physiological metabolism.

Not only those actually working with sources of ionizing radiation but personnel in adjacent rooms (clerical and administrative) may receive radiation. Accordingly, the Sanitary Regulations for Working with Radioactive Substances and Sources of Ionizing Radiation issued by the U S S R Ministry of Health and State Committee of the Council of Ministers on the use of atomic energy established the following three categories of irradiation: (1) category A - occupational irradiation of persons in direct contact with sources of ionizing radiation; (2) category B - irradiation of persons working in areas adjacent to those in which radioactive sub-

stances and sources of ionizing radiation are handled but who do not themselves touch the materials (includes those in administrative, service, and supply areas, in all buildings and outdoors within a sanitary protective zone); (3) category C - irradiation of all age groups of the population (including those living in areas bordering on a sanitary protective zone, even if the adult element belongs to either category A or B).

The maximum permissible doses for external irradiation are presented in Table 1.

Table 1

Maximum Permissible Doses of External Irradiation  
(in biological equivalents of rad — ber)

Category of irradiation	Maximum permissible dose	
	ber/week	ber/year
A	0.1	5
B	0.01	0.5
C	0.001	0.05

The MPD for the population as a whole is less than twice the minimum value of the natural background regarded as equal to 0.026 rad/year and 100 times less than the MPD for occupational irradiation.

Depending on working conditions, irradiation with a dose in excess of the MPD is permitted in one day or week of work. According to the Sanitary Regulations, it is permissible to receive a dose not in excess of 3 ber per quarter (13 consecutive weeks), regardless of time of irradiation (even a single exposure), but the working conditions during the following weeks must be such that the total dose not exceed 3 ber.

The total dose D for occupational irradiation must not exceed  $D \leq 5 (N-18)$  ber, where N is the person's age (18 is the minimum age; younger persons are not permitted by Soviet law to work with radioactive substances).

Table 2 gives the values of MPD of different kinds of radiation in relation to their relative biological effectiveness (RBE).

Table 2

Maximum Permissible Dose Rates for Different Kinds of Radiation (in rad/week)

Kind of radiation	RBE	Categories		
		A	B	C
X-rays and gamma rays	1	0.1	0.01	0.001
Beta Particles and electrons	1	0.1	0.01	0.001
Protons and Alpha particles	10	0.01	0.001	0.0001
Multicharged ions and release of atoms	20	0.005	0.0005	0.00005
Thermal neutrons	3	0.033	0.0033	0.00033
Rapid neutrons	10	0.01	0.001	0.0001

In determining the maximum permissible levels of internal irradiation, account is taken both of the total absorbed dose omitted by a given radioactive isotope throughout the time it remains within the body and of the organ which is critical for that isotope because the different radioactive substances concentrate preferentially in certain organs (cf. article on "Radiation Toxicology"). A critical organ is one in which storage of a radioactive isotope results in the maximum injury to the organism as a whole.

The following three groups of organs are considered critical in calculating the maximum permissible concentration (MPC) of radioactive substances: group 1 - entire body, gonads, crystalline lens, and hematopoietic organs; group 2 - muscles, fatty tissue, liver, kidneys, adrenal and prostatic glands, gastrointestinal tract, and lungs; group 3 - skin, thyroid, and bones. Table 3 presents the accepted MPD values of internal irradiation for different groups of critical organs and irradiation categories.

Table 3

Maximum Permissible Doses of Internal Irradiation

Irradiation category	Group 1		Group 2		Group 3	
	ber/week	ber/year	ber/week	ber/year	ber/week	ber/year
A	0.1	5	0.3	15	0.6	30
B	0.01	0.5	0.03	1.5	0.06	3
C	0.001	0.05	0.01	0.5	0.02	1



For practical purposes it is important to know the MLC in air and water of the radioactive isotope whose entrance into the body with the daily intake of water or air does not create doses in excess of the MLD in critical organs or in the body as a whole. The initial data for this calculation come from a knowledge of the critical organ for a given isotope (determined experimentally in animals) and the amount (activity) of the isotope that creates the MLD in a critical organ. The daily intake of the isotope with water or air must be such that after 30 years of work the isotope activity in the body will be no higher than the value at which is created the MLD established for the particular group of isotopes and category of irradiation (Table 3). The Sanitary Regulations contain tables showing the MLD in water and air for most of the presently known radioactive isotopes.

The maximum permissible levels of contamination of work surfaces, hands, and clothing are determined in similar fashion. In doing so account is taken of the portion of the active substance that might enter the body from contaminated hands or work surfaces.

With simultaneous action of several radiation factors, the total dose from all of them must not exceed a single MLD.

The established MLD for both external and internal irradiation do not include the natural background or the

radiation received in the course of certain medical procedures (cf. the article "Doses of Ionising Radiation").

General principles of protection against radiation. The main purpose of protective measures in working with radioactive substances or sources of penetrating radiation is to prevent the substances from entering the body and keeping the dose of external irradiation to the maximum permissible levels. Protection from external irradiation is afforded by stationary or movable enclosures which ensure safety of working conditions.

Since the range of alpha particles (cf. "Alpha Rays") emitted by presently known radioactive isotopes is very short, no more than 9 cm in air or 0.01 cm in tissue, clothing and rubber gloves provide full protection against these particles. If one stands beyond the range of alpha particles in air, no harm will result even if the body is unprotected.

To protect the body from external irradiation with beta particles (cf. "Beta Rays"), radioactive substances must be handled behind special shields (screens) or in special cabinets. The thickness of the protective enclosure must be greater than the maximum range of the beta particles. The maximum ranges of beta particles with energies of 0.5, 1.0, and 2.0 Mev are 119, 306, and 710 cm, respectively, in the air, and 1.87, 4.6, and 11.1 cm in soft tissue. Plexiglas, aluminum, and glass are the usual protective materials. The thickness of

protection  $d$  in  $\text{g/cm}^2$  may be determined from the following approximate formula:

$$d = 0.54 \cdot E_{\text{max}} - 0.15,$$

where  $E_{\text{max}}$  is the maximum energy of the beta spectrum of the given radioactive isotope in mev.

The following formula is used to calculate the degree of protection against X- or gamma radiation:

$$D = D_0 B(h\nu, \mu d, Z) e^{-\mu d},$$

where  $D_0$  is the dose at a given point in the absence of protection;  $D$  is the dose of radiation at the same point created after penetration through protection  $d$  cm thick;  $\mu$  is the linear attenuation of narrow-beam radiation factor;  $B(h\nu, \mu d, Z)$  is the growth factor, which takes into account the role of scattered radiation produced in the shield by the interaction of the radiation and the substance (Of. "Ionizing Radiation").

To facilitate the calculations, some handbooks provide various nomograms and tables for direct determination of the thickness of protection  $d$  against radiation of different spectral composition under different working conditions.

Theoretically, any material can be used for protection against X- or gamma rays. However, in choosing material one must be guided by considerations of design, economy, and requirements for bulk and weight.

Sometimes in working with sources of gamma radiation (activity 10 to 30 meq of radium) the conditions are such that it is impossible to set up a stationary shield (e.g., in recharging the unit, withdrawing a radioactive preparation from a container, calibrating an instrument, detecting flaws with an open source, preparing applicators and moulages, etc.). In such cases one can use movable shields (Fig. 1) or, as they say, "protection by distance" or "protection by time", meaning that all open sources of gamma radiation should be handled with long tongs or holders because the radiation dose decreases in inverse proportion to the square of the distance. Furthermore, a given operation should be performed only in that interval of time during which the worker does not receive a dose in excess of the norms established by the Sanitary Regulations. Such work must be monitored by a health physicist.

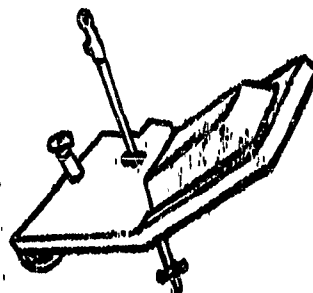


Fig. 1. Table shield with an CUN-type holder.

Furthermore, no unauthorized persons are allowed to remain there, and the area where the dose exceeds the MPD must be closed off. When the activity of the source is  $M$  mEq of radium, the distance at which an MPD is created is

$$R = \sqrt{\frac{0.4 \cdot M \cdot t}{D}} \text{ cm,}$$

where  $D$  is the MPD per workday and  $t$  is the time in hours during which an open source is handled.

The time during which a worker may be near an open source to perform an operation is

$$t = \frac{D \cdot R^2}{0.4 \cdot M} \text{ hours,}$$

where  $R$  is the distance (in cm) from the worker and  $D$  is the MPD per workday.

Protection against neutrons is calculated from the appropriate formulas or nomograms. Substances with low atomic numbers are used as protective materials because at each collision with a nucleus the neutron loses part of its energy, the more so the closer the nuclear mass is to the neutron mass. Water or concrete is normally used for protection against neutrons. Having lost its energy in the protective substance as it interacts with the nuclei of the atoms, the fast neutron is transformed into a thermal neutron which is captured by the nuclei of the atoms while emitting gamma quanta.

It will be noted that there is virtually no pure neutron flux. It is generally known that nuclear reactors, accelerators, and radium-beryllium preparations are neutron sources. Besides neutrons, all these sources have powerful gamma-ray fluxes that are produced during the fission processes or from the decay of fission products. Gamma rays are produced in accelerators and radium-beryllium preparations by nuclear reactions which yield neutrons; they are also emitted by the products of radium decay. Thus, in designing protection against neutrons one must at the same time provide protection against gamma radiation (cf. "Neutron Radiation").

Protection against external radiation from open sources also entails proper planning and equipping of work areas, including ventilation, so as to prevent radioactive substances from penetrating the body. The requirements vary with the nature of the operations to be performed with the particular isotope, its activity and toxicity. All work with radioactive isotopes are divided into three classes according to the toxicity and activity of the substances at the work place (Table 4).

Table 4

Activity at Work Places for Different Classes of Work

Toxicity group	Activity at work place, $\mu\text{C}$		
	Class 1	Class 2	Class 3
A	> 10	0.01 - 10	0.0001 - 0.01
B	> 100	0.1 - 100	0.001 - 0.1
C	> 1000	1 - 1000	0.01 - 1
D	> 10000	10 - 10000	0.1 - 10

Class 3 work can be done in ordinary chemistry laboratories. Operating personnel must wear a gown, bleached moleskin cap, and rubber or vinyl chloride gloves.

Class 2 work must be done in specially equipped areas isolated from the other areas. The floor is covered with masticated rubber while the walls are painted from top to bottom with an oil paint. Radioactive substances are handled in special boxes (Figs. 2 and 3) or under exhaust hoods. The boxes and hoods are equipped with exhaust fans and filters to trap the radioactive aerosols.

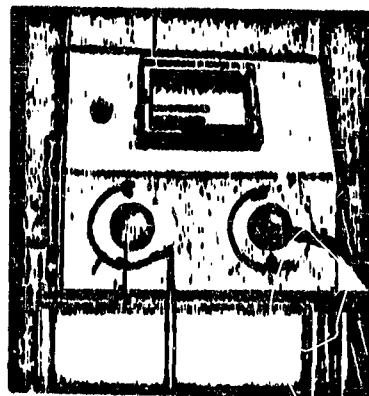


Fig. 2. Box for handling radioactive substances. Tong-like manipulators are mounted in the front of the box.



Fig. 3. Mechanical manipulator for handling very active isotopes.



Radioactive substances are handled with tongs and pincers (Fig. 4).

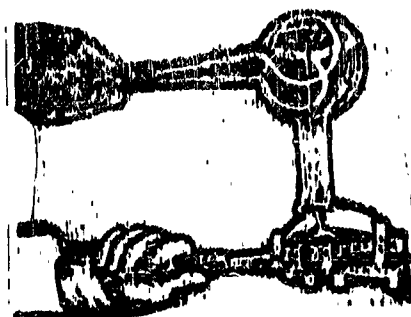


Fig. 4. Tongs for handling radioactive substances.

Operating personnel wear a gown, bleached moleskin cap, rubber-soled shoes, and rubber or vinyl chloride gloves. A plastic apron, oversleeves, and, at times, a "Lepestok" respirator (to protect the respiratory organs) are also used (Fig. 5).



Fig. 5. "Lepestok" respirator.

In class 2 laboratories it is desirable to provide facilities for taking a shower when the work is finished.

Class 1 work is done in areas divided into three parts in such a way that the sources of radiation are isolated from the places where the people work regularly. These areas are in a special building or isolated wing of a building with a separate entrance. One part of the area (zone 1) includes the space for the equipment, boxes, communications, etc., which are the sources of radioactive contamination. Zone 2 is used for repair work, loading and unloading of active materials, or auxiliary operations involved in opening equipment and decontamination. Zone 3 contains shielded areas where most of the people stay. Zones 2 and 3 are connected by a sanitary enclosure in which additional means of individual protection are kept and, when necessary, personnel leaving zone 2 can be given sanitary processing.

In the areas where class 1 work is done the floors are covered with masticated rubber or tile while the walls are faced with glazed tiles or masticated rubber. The ceilings are painted with an oil paint.

A class 1 laboratory must have a sanitary passageway. Operating personnel wear special underwear, moleskin overalls, plastic apron, and oversleeves. All work is done in special boxes. There are exhaust fans with filters all over

to purify the air. All repair and decontamination work is carried out on the zone 2 side. Special air suits are worn to prevent radioactive substances from penetrating the body.

Class 1 and 2 laboratories must systematically monitor the external gamma-ray background and the contamination level of work surfaces, atmospheric air, clothing, hands, and body of the workers.

Protection against X-rays and closed sources of gamma radiation. The various devices are either stationary or movable. The former includes protective walls, floor and ceiling coverings, doors and doorways, viewing windows, stationary equipment for work with gamma-ray sources, etc. Movable devices include screens, casing of X-ray tubes, tubules and diaphragms that limit the rays, portable machines for work with gamma-ray sources, containers for shipping and storing radioactive preparations, etc. The devices are selected in accordance with the purpose for which the radiation sources are to be used.

A distinction must be made between the protective systems used in: (a) X-ray diagnostic rooms; (b) X-ray treatment rooms; (c) gamma therapy; (d) therapy with high-energy particle accelerators; (e) detection of flaws in manufactured goods with X-rays and gamma rays.

Protection in X-ray diagnostic rooms. Apparatus producing

X-radiation with energy up to 110 kev are most commonly used for diagnostic purposes. Stationary protection of walls and ceilings as well as local guards are employed to shield the patient, technicians, and personnel working in adjacent areas from unused radiation.

Protective devices of the general (stationary) type may not be required in buildings with thick brick walls if they are designed properly. Otherwise stationary protection is calculated from specifications for the maximum nominal voltage with due regard for the distance from the X-ray tube.

Local protection in roentgenography includes the protective casing of the X-ray tube, with a window for focusing the beam only in the desired direction; diaphragm limiting and forming the irradiation field; tubule guarding against scattered radiation arising in different parts of the X-ray tube, at the edges of the viewing window and in the diaphragm; screen near the control panel to protect the technician.

Other devices used in roentgenoscopy include lead glass applied to the luminous screen on the side of the observing physician; shields of lead-lined rubber around the frame with a screen to protect the physician's body from scattered radiation; shields protecting the physician's legs from scattered radiation; protective lead-lined rubber clothing, gloves, aprons.

The radiation dose is reduced during fluoroscopy by increasing the brightness of the screen, increasing filtration of rays (to 3 mm of Al), reducing current through the tube, employing image converter tubes.

The principal protective materials used in enclosures are lead plate (casing, tubules, diaphragms), lead glass, lead-lined rubber.

The lead equivalent of the walls of protective enclosures must ensure a dose rate below the MFD. The dose rate for an enclosure varies both with the size of the lead equivalent of the wall and with the distance from the source. In addition, there is a different MFD for the different categories (cf. above). Therefore, the lead equivalent of general stationary enclosures is generally calculated for each case individually. For protection against direct radiation from a 110 kv X-ray machine in relation to the above-mentioned factors, the lead equivalent of the walls, ceiling, and floor may range from about 1 to 5 mm of Pb. The lead equivalent of the devices for local protection (lead glass for screens, hood, shield, apron, etc.) varies within approximately the same limits. Since the protection standards are reviewed from time to time, the lead equivalents of the various local shielding devices should also be reviewed for each item separately (cf. "X-ray Room").

Protection in X-ray treatment rooms. Apparatus producing X-radiation with energy up to 200 kev are generally used for roentgentherapy. More powerful machines yielding radiant energy of several million electronvolts are now becoming increasingly available.

Radiation protection in treatment rooms is the same regardless of the energy used except for the lead equivalent of the protective devices. It is characteristic of an X-ray treatment room, unlike a diagnostic room, that medical personnel are not allowed to remain during a session while the X-ray tube is functioning. The patient is generally irradiated in a booth as the technician and apparatus control stay behind a protective wall.

Stationary protective enclosures consist of protective walls, ceiling, floor, doors to the booth, and viewing window. The protection is based on the maximum possible voltage in the X-ray tube and the distance from it to the place where the medical personnel stay. These enclosures are designed to protect both personnel and adjacent rooms.

The lead equivalents of stationary enclosures vary with the factors mentioned above. For example, they may range from about 4 to 6 mm of Pb for radiation from a 200 kv machine.

As in the case of diagnosis, the patient is protected against excess radiation by the casing of the X-ray tube, diaphragma, and tubule.

Protection in gamma-therapy rooms. The usual gamma-ray sources are  $\text{Co}^{60}$  (energy - 1.33 and 1.17 mev) and  $\text{Cs}^{137}$  (energy - 0.663 mev). The protective casing of the machine in nonoperating position lowers the radiation dose rate in all directions to 2 mr/hour or less at a distance of 1 m from the source. The machine must be used in a specially constructed room with protective walls and ceiling because when in operating position (while the patient is being irradiated) the beam may be directed to the floor, ceiling, or toward the adjacent rooms. The lead equivalent of the stationary enclosures of protective booths for gamma therapy depends on the amount of activity of the radiation sources, distance from source to personnel station, and size of permissible dose rate behind the enclosure. For example, if there is a second floor above the room where a gamma apparatus with cobalt source possessing the activity of 400 g-eq of radium is located, the floor and ceiling between the two stories must have protection equivalent to 24 cm of Pb. A floor and ceiling of cement with a density of  $2.3 \text{ g/cm}^3$  should be about 1200 mm thick.

The walls and ceiling need not be so thick in a room with a rotary machine if a protective block counterpoise is placed behind the patient in the path of the beam. If the counterpoise attenuates the beam, say, 5000 times (steel layer 20 cm thick), the thickness of the cement ceiling and floor in the example cited above can be decreased to 600 mm. This thickness is required not only to attenuate the direct beam passing through the counterpoise, but also to protect personnel on the floor above from scattered radiation.

The entrance to the treatment room is usually protected by a maze arrangement because of the great quantity of radiation emitted by  $\text{Co}^{60}$  and  $\text{Cs}^{137}$  sources. This considerably reduces the consumption of lead for the door and makes it lighter in weight. The maze entrance is generally interlocked with the machine in such manner that when the source is open the booth cannot be entered. At the same time signals indicate the position of the source.

The patient can be safely observed through a viewing window (in the protective wall) shielded by lead glass panes with a transparent, very dense fluid sometimes placed between them. Television receivers, periscopes, etc. are used to observe patients as they are irradiated.



Concrete, barite concrete, and brick are used for the stationary protective enclosures, lead for the protective casing of the X-ray machine and block counterpoise. Wolfram and uranium, which have strong shielding properties, are also used. Utilization of these materials greatly reduces the bulk and weight of the protective devices. The following ratios apply to gamma radiation of  $\text{Co}^{60}$ : equivalent thickness of lead and wolfram - 1.4 cm : 1 cm; equivalent thickness of lead and uranium - 1.8 cm : 1 cm.

Protection in rooms with accelerators. The general arrangement of the protective devices for work with accelerators (cf. "Charged Particle Accelerators") is similar to that employed in roentgentherapy. The accelerators are surrounded by protective walls and ceilings and floors.

The accelerator is provided with local protection depending on its design. This protection either encircles it or only goes around the window, blocking excess and scattered radiation. The direct beam behind the patient is blocked by the protective enclosure. The room needs overall shielding to remove the scattered radiation escaping from the edges of the diaphragms, patient's body, and parts of the enclosure on which the direct beam falls behind the patient.

The thickness of the protective sheets of the enclosures is calculated from the quantity of bremsstrahlung emitted by the accelerator.

Protection against radiation from accelerators of different design must be individually determined, taking into account the nature, energy, and intensity of the radiation emitted.

Protection against X-rays and gamma rays used for industrial and research purposes. X-ray diffraction and spectral analysis is performed with apparatus producing thin, directed beams of X-radiation with energy no higher than 80-100 kev, sometimes of very great intensity. Therefore, careful attention must be paid to local protection and the actual operating technique and handling of the apparatus. The greatest danger is accidentally placing the hands or part of the body in a direct beam, which may cause severe local radiation lesions (cf. "Radiation Burns").

X-ray flaw detection is based on the photographic method involving a fluorescent screen and ionisation indicators. Under stationary conditions it is ordinarily used in special booths similar to those employed in roentgentherapy and providing protection against both direct and scattered rays. In industry use is made of a mobile unit, portable screens, and other temporary means of enclosing the work area. The X-ray tube is placed in a protective casing. Protective en-

closures, fluorescent screens, and ionization indicators are part of the standard equipment. The purpose of the enclosures is chiefly to protect the technicians from the scattered radiation proceeding from the object and edges of the diaphragms and tubules.

X-irradiation of biological objects for research purposes is generally carried out in rooms similar to those used in roentgentherapy.

Industrial and research gamma irradiation units are comparable to those used for gamma therapy except that the protective enclosures are generally included in the design of the machine.

Gamma units for flaw detection emit a directed, limited beam or they allow the radiation source to be pushed forward to produce circular transillumination. That is why gamma defectoscopy under stationary conditions is carried out in special protective booths. When a gamma unit is used directly in a shop, it is difficult to install a protective enclosure because of its great weight. All except the technicians, who use remote-control devices, must leave the area.

The gamma apparatus used for radiological experiments, cold sterilization, radiochemical investigations, etc. differ

from the other types in that volume irradiators are used instead of the point source employed in gamma machines for therapy and flaw detection. In planning protection against radiation from such machines one must take into account both the radiation rate and the operating conditions (e.g., need to change the objects frequently, size of the irradiator which is sometimes considerable).

Blocking devices and signal systems are highly important. Whereas lead, less commonly wolfram and uranium, are used as shielding materials in the construction of gamma machines for flaw detection and therapy, brick, concrete, and other building materials are used in gamma machines of the stationary type. Lead, wolfram, and uranium are only used in the construction of mobile units.

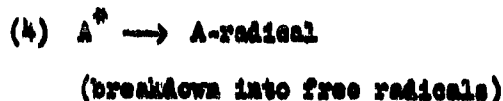
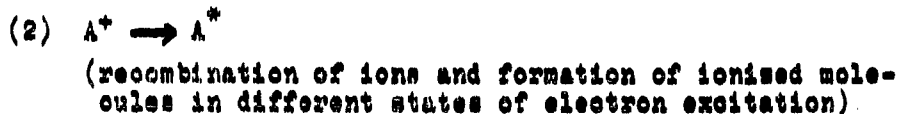
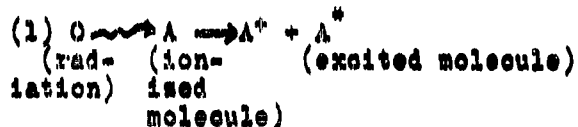
Transportation of gamma sources. These substances are shipped, as a rule, only in special containers conforming to the standards set by the State Committee of the Council of Ministers on the use of atomic energy and the U.S.S.R. Main State Sanitary Inspector. Gaseous and liquid radioactive substances must first be packed in hermetically sealed boxes and then, depending on special requirements, placed inside containers with shielding material determined by the amount of the substance and radiant energy. Solid radioactive sources in ampule can be shipped in protective containers

with no other packing.

Of the articles on "Radiation Hygiene" and "Radiobiology".

Chemical (biological) protection against radiation.

Chemical radiation protection involves the introduction of certain substances into the body before radiation in order to weaken its biological effect. These "protectors" are used in roentgentherapy and curiatherapy, in repair work in laboratories and industrial plants utilising ionising radiation and radioactive isotopes. Their mechanism of action is very closely related to the primary physicochemical and biochemical reactions that follow the irradiation of tissue (cf. "Radiobiology"). Some aspects of the mechanism of action may be understood by considering a very simple model - roentgen (gamma) irradiation of substance A dissolved in water. The following reactions will occur:



- (5)  $A^* \longrightarrow A\text{-radical}$   
(conversion into thermal energy)
- (6)  $A^* + A \longrightarrow A + A + \text{heat}$   
(concentrated extinguishing)

Similar processes will take place when the water itself is irradiated. It is necessary to bear in mind that: (a) all energy absorbed by tissue is distributed proportionately to the mass of the substances composing the tissue; (b) most tissues contain large amounts of water; (c) aqueous phases are directly contiguous to the surfaces of the most varied molecules in the living cell; (d) radicals formed in the aqueous phase may react directly with biologically significant molecules; (e) free radicals are complexes with anomalous valence which possess a marked affinity for combination, but do not carry an electric charge and are not free ions; (f) with the irradiation doses that are normally used in biological experiments, the number of free radicals formed grows linearly with increase in dose; (g) molecular oxygen plays an exceptionally important role in the formation of free-radical states.

The following approaches to the problem of devising chemical radiation protection are suggested by the foregoing considerations: (a) reduce the yield of radicals, peroxides, and free-radical states resulting from irradiation by temporarily decreasing the concentration of oxygen or water with

chemical compounds; (b) decrease the radiobiological effect by introducing into the organism compounds capable of reacting with the radicals formed; (c) introduce into the organism compounds capable of reacting temporarily with active groups of molecules in the cell ("protection" of the most vulnerable links in the biochemical processes for the period of irradiation); (d) use compounds capable of rapidly absorbing radiation of water or preventing the migration of excitation energy from the molecules of water to the molecules of the dissolved substance; (e) search for substances - "extinguishers" - which aid the conversion of ionisation and excitation energy into thermal energy.

Methods of chemical protection include the administration of vitamins, hormones, coenzymes, and certain biological stimulants ("biological" protection). These substances are administered several times a few days before irradiation.

All protective substances are classified with various chemical compounds. For example, investigators have identified such groups as the aminothiols, amines not containing the SH group (biogenic amines), sulfur-containing amino acids, cyanogenetic compounds, etc. These substances are further divided into two groups on the basis of the time factor: (1) chemical substances introduced a short time before irradiation; (2) protectors with protracted action, which are introduced into the

organism at various times (up to 30 days) before irradiation. The latter group includes the vitamins and hormones.

There are dozens of chemical compounds known to provide animals with some degree of protection against lethal doses of x-rays and gamma rays. For example, 50% of rats injected before irradiation with L-cysteine or  $\beta$ -mercaptoethylamine survive as compared with a 100% mortality rate for the controls.

Some of the protectors, e.g.,  $\beta$ -mercaptoethylamine (mercamine, becapter, cysteamine),  $\beta$ -mercaptopropylamine (propamine), etc., have been approved by the Committee on Pharmaceuticals. Mercamine and propamine alleviate some symptoms of radiation sickness (q.v.) in persons receiving roentgen- or curietherapy.

The following general considerations apply to the mechanism of action of the protectors: (a) almost all are effective only if administered prior to irradiation and are ineffective even if administered immediately afterward; (b) all the protectors investigated are almost completely ineffective if irradiation is carried out in an atmosphere with high oxygen content; (c) most of the protective compounds protect the organism from oxygen poisoning, yet if rats, for example, are injected with them, oxygen utilization by the whole organism decreases; (d) almost all the protectors investigated are antioxidants, and the formation of peroxide-like compounds diminishes after they are introduced into the organism.



An interesting feature of many of these chemical compounds is that the maxima of their spectra of phosphorescence are very close to the spectra of deoxyribonucleic acid (q.v.). This suggests that irradiation may stimulate the migration of energy from the metastable state of DNA to the protectors.

The following is an example of the action of protectors with properties characteristic only of certain classes of compounds. It has been found that in the aminothiols series (mercapamine, etc.) compounds with the general formula



where x is no higher than 3, possess protective properties.

The mechanism of protective action of the vitamins and hormones has not as yet been thoroughly investigated. General radioresistance is apparently increased in various ways. For example, repeated administration of vitamin P (citrin) together with ascorbic acid combats permeability of capillary walls, reduces the number of hemorrhages, and increases the survival rate of animals exposed to X- or gamma irradiation in sublethal doses.

We can expect better results by simultaneously using several protectors acting on different links in the primary physicochemical, radiochemical, and biochemical reactions developing after irradiation. The results have been particularly good when the protectors were combined with therapeutic measures.

### Bibliography

#### Radiation Protection (Physical)

Belousova, I. M. and Yu. M. Shukkenberg. Natural Radioactivity. Moscow, 1961.

Bihorgal', A. V., U. Ya. Margolia, and Ye. I. Vorob'yev. Protection against X-rays and Gamma Rays, Moscow, 1960.

Bihorgal', A. V., V. I. Sinitin, and N. I. Loshchinskiy. Iodine Gamma Machines, Moscow, 1960.

Corodinskiy, S. M. and G. M. Parkhomenko. Labor Hygiene in Handling Radioactive Isotopes, Moscow, 1955.

Gusev, N. G. Handbook on Radiation Protection, Moscow, 1956.

Gusev, N. G. and Ye. Ye. Kovalev. Nomograms for Calculating Protection against the Gamma Rays of Ra, Co<sup>60</sup>, Cs<sup>137</sup>, and Pu<sup>239</sup>, Moscow, 1959.

Shielding of Nuclear Reactors, transl. from the English, Moscow, 1958.

Regulations for Shipping Radioactive Substances, Moscow, 1961.

Prince, D., K. Horton, and K. Spinney. Radiation Protection, transl. from the English, Moscow, 1959.

Radiation Medicine, ed. by A. I. Burnashev and A. V. Lebedinskiy, Moscow, 1960.

Sanitary Regulations for Work with Radioactive Substances and Sources of Ionizing Radiation, Moscow, 1960.

#### Radiation Protection (Biological)

Romantsev, Ye. F. and A. V. Savich. Chemical Protection against Ionizing Radiation, Moscow, 1958.

Chemical Protection against Ionizing Radiation, ed. by V. S. Bulabukhi, Moscow, 1960.

Bacq, Z.-M. and P. Alexander. Principles de radiobiologie, Paris, 1955.

5214  
CSC: 8309-D

-END-